www.bsc.es

Montreal, 21st June 2017

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Sources of the SST bias in Tropical Atlantic in EC-Earth

Eleftheria Exarchou

Chloe Prodhomme, Laurent Brodeau, Virginie Guemas
Francisco Doblas-Reyes

PREFACE: Enhancing PREdiction oF tropical Atlantic ClimatE and its impacts

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

- To reduce uncertainties in our knowledge of the functioning of tropical Atlantic climate, particularly of climate-related ocean processes and dynamics, coupled ocean, atmosphere, and land interactions; and internal and externally forced climate variability;

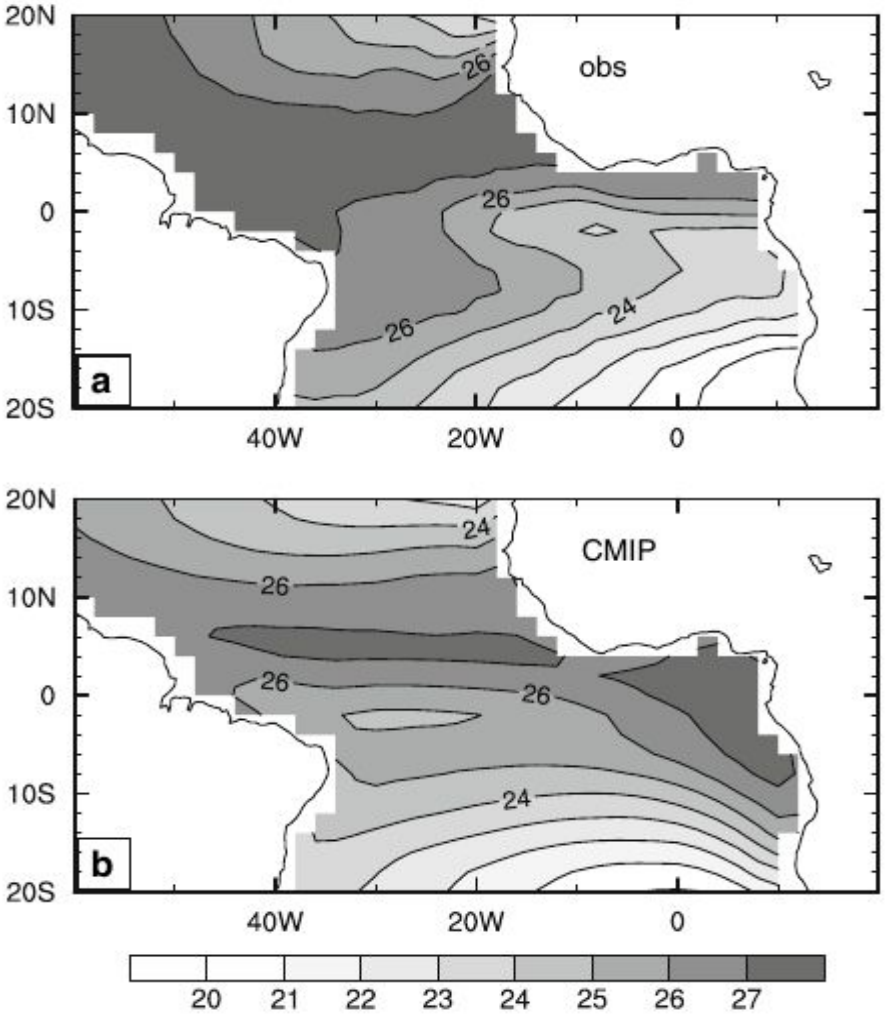
- To better understand the impact of model systematic error and its reduction on seasonal-to-decadal climate predictions and on climate change projections;

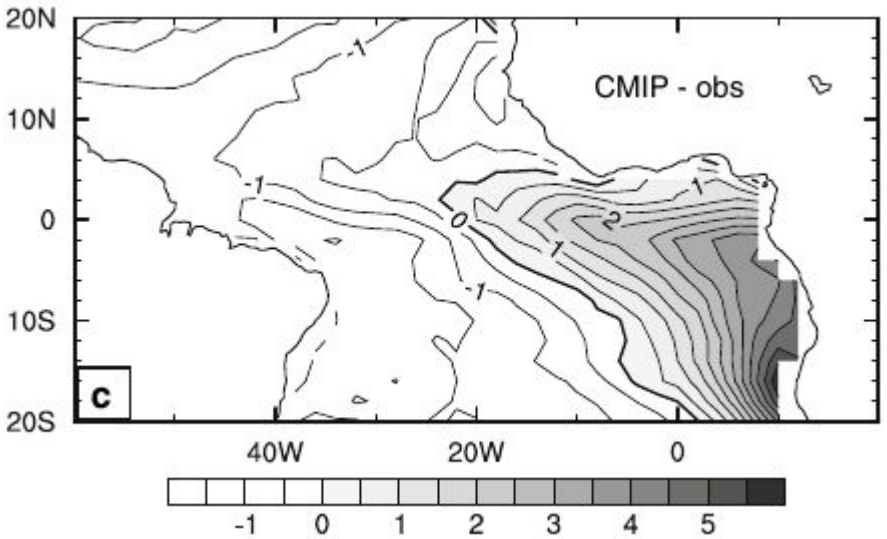
- To improve the simulation and prediction of tropical Atlantic climate on seasonal, and longer time scales, and contribute to better quantification of climate change impacts in the region;

- To improve understanding of the cumulative effects of the multiple stressors of climate variability, greenhouse gas induced climate change (including warming and deoxygenation), and fisheries on marine ecosystems, functional diversity, and ecosystem services (e.g., fisheries) in the tropical Atlantic;

- To assess the socio-economic vulnerabilities and evaluate the resilience of the welfare of West African fishing communities to climate-driven ecosystem shifts and global markets.

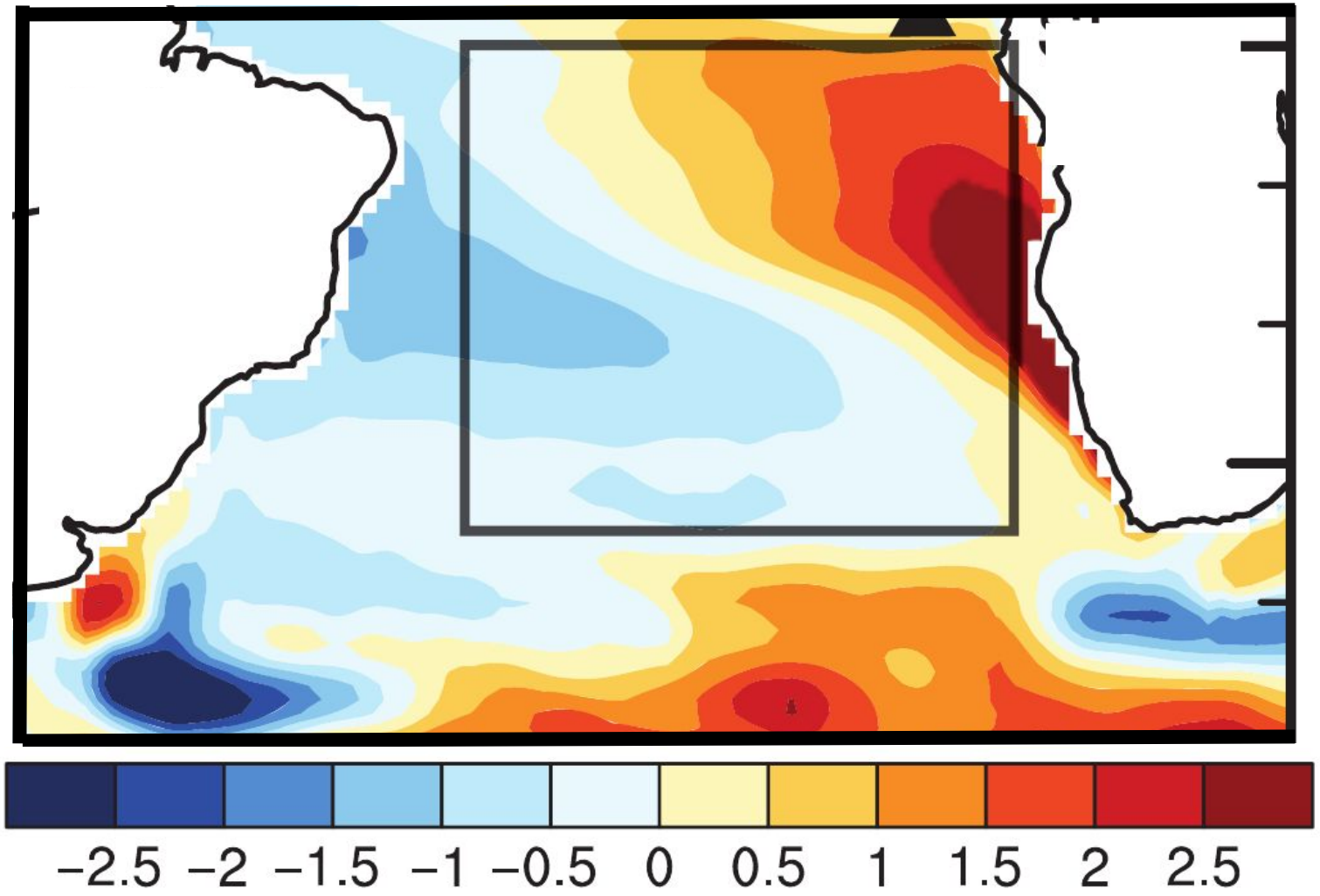
SST bias in Tropical Atlantic (CMIP3)





Richter et al, 2008

SST bias in Tropical Atlantic (CMIP5)



Richter et al, 2015

Mechanisms discussed in the past

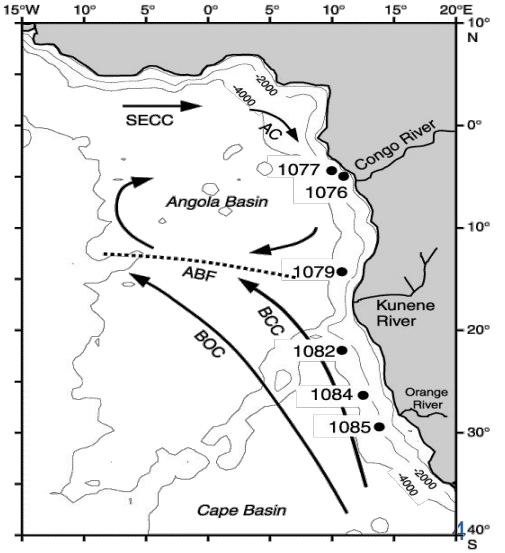
- **Coarse horizontal/vertical atmosphere resolution** → weak alongshore wind and windstress curl → weak upwelling/vertical advection in the ocean → warm SST bias

- **Coarse horizontal/vertical atmosphere resolution** → insufficient representation of low stratocumulus clouds at eastern boundaries → overestimation of solar insolation → warm SST bias

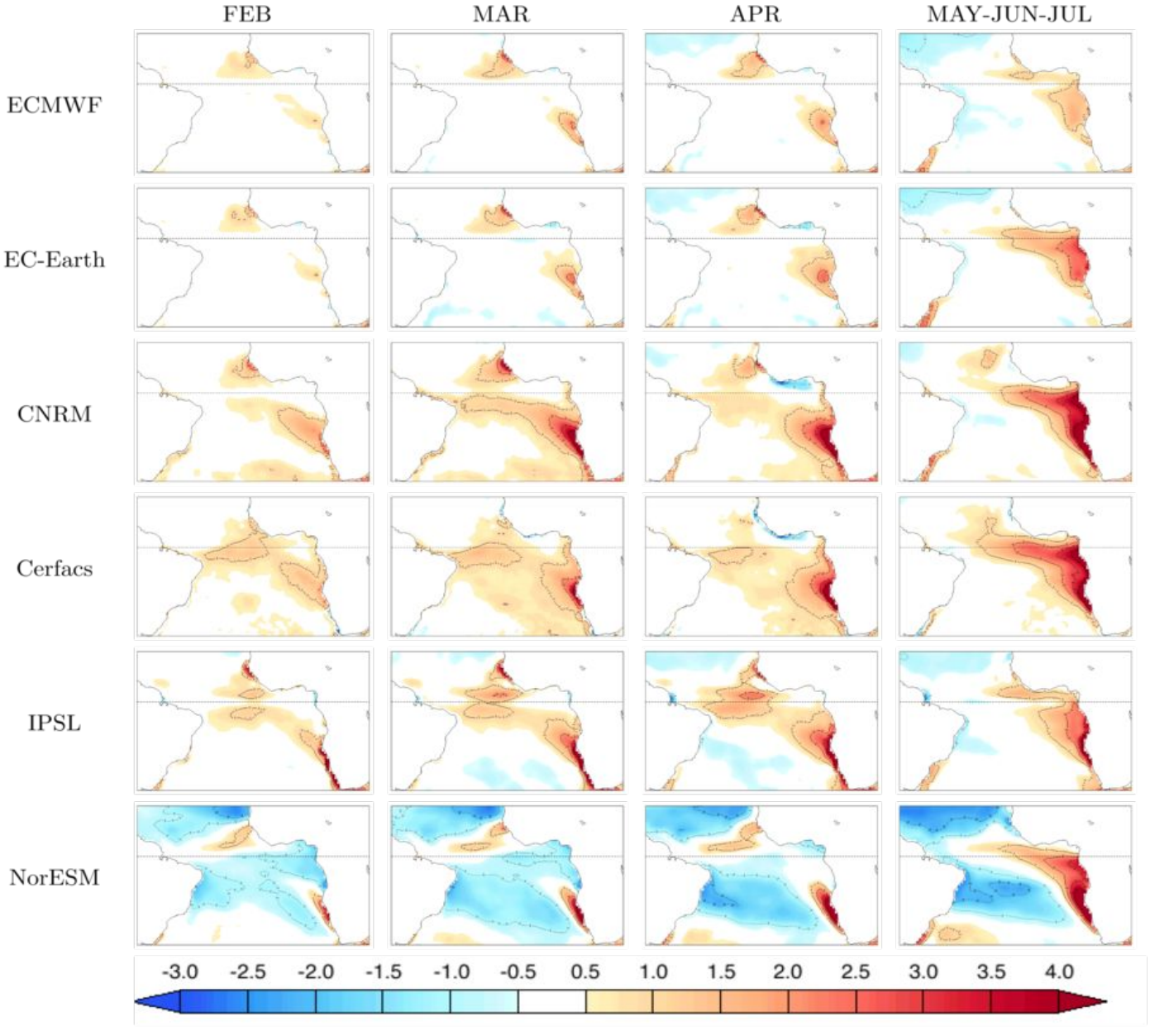
- **Coarse horizontal resolution in the ocean** → insufficient mesoscale and sub-mescoscale ocean eddies → inadequate representation of eddies in the heat budget → warm SST bias (under debate)

- **Southward displacement of a Angola Benguela surface front** → weaker transports of cold water from the south to the South-East Tropical Atlantic → stronger transport of equatorial warm water to the South-East Tropical Atlantic → warm SST bias

http://www-odp.tamu.edu/publications/175_SR/chap_10/c10_f1.htm



SST drift in seasonal forecasts

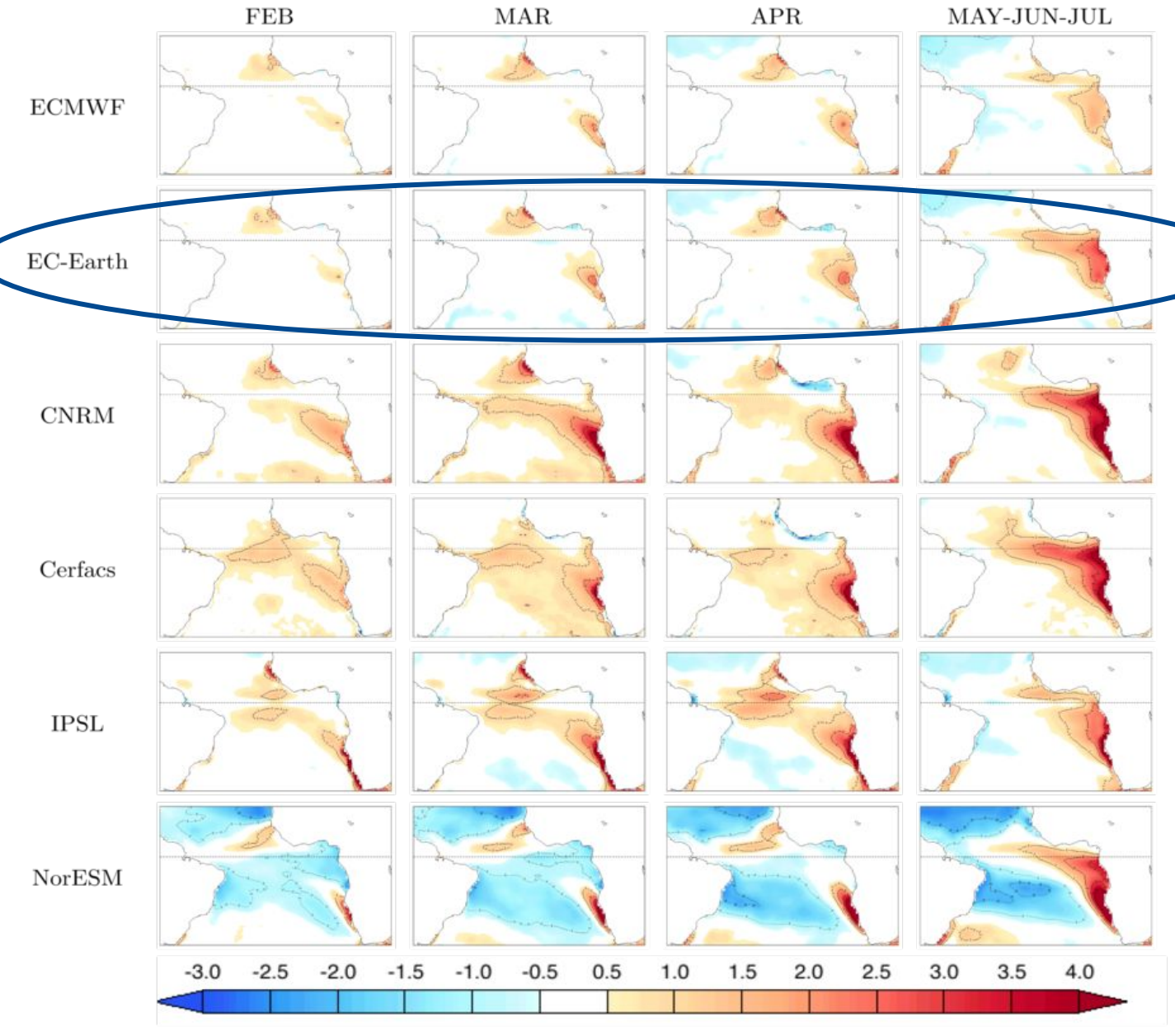


Poster of Aurore Voldoire

"SST bias development in the Tropical Atlantic in PREFACE coordinated experiments"

SST drift in seasonal forecasts

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA



Poster of Aurore Voldoire

"SST bias development in the Tropical Atlantic in PREFACE coordinated experiments"

PREFACE

Methodological approach - model

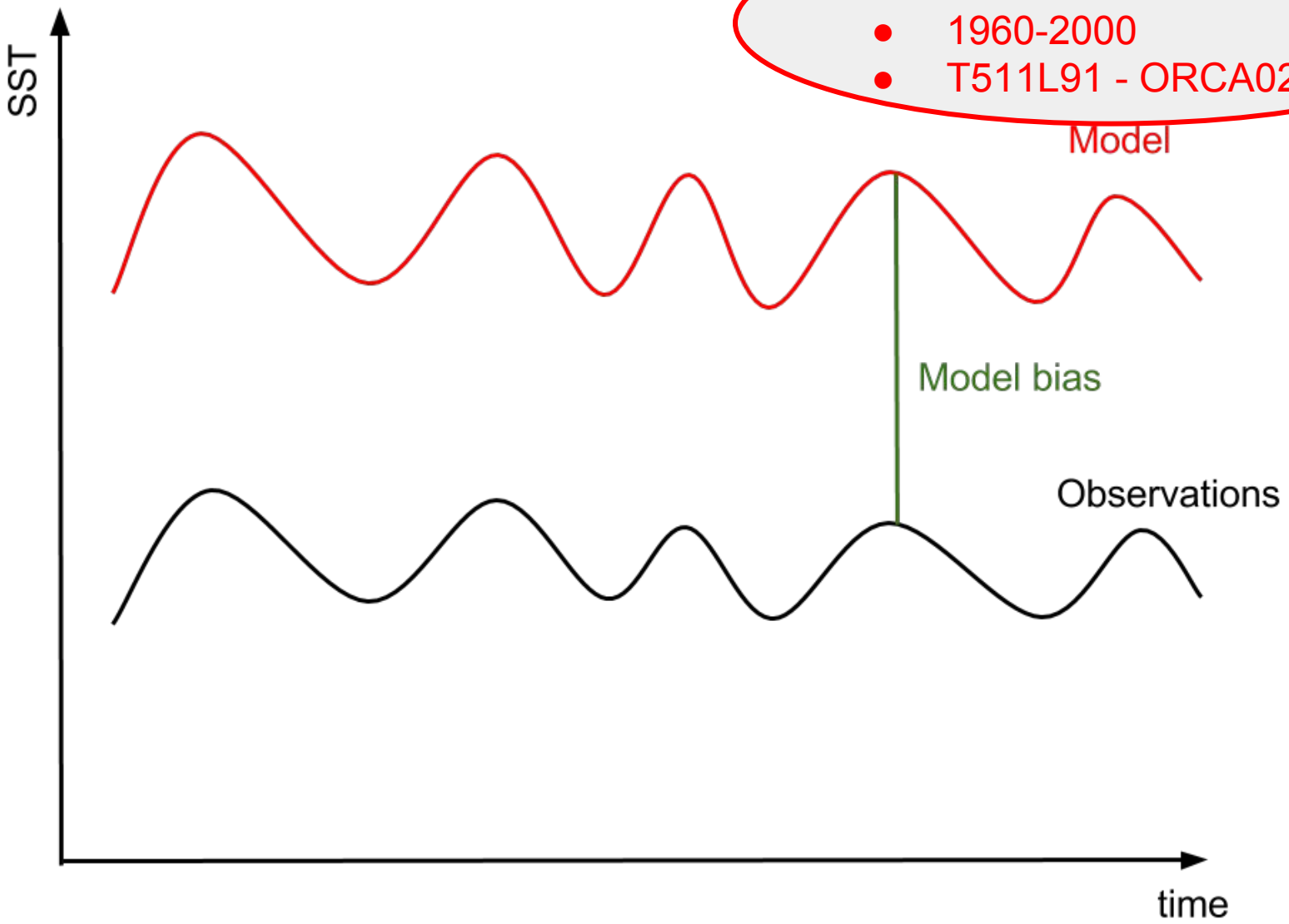
EC-Earth version 3.1 (version 2.3 - CMIP5, Hazweleger et al. 2012)

- Atmosphere model is IFS, T511 (HR-0.35º), T255 (LR-0.7º), 91 vertical levels (up to 1Pa)
- Ocean model is NEMO version 3.3.1 (Madec 2008), in two configurations: ORCA025L75 (HR-0.25º,75 vertical levels) and ORCA1L46 (LR-1º,46 vertical levels)
- Sea-ice model is LIM2 (Louvain-la-Neuve Sea Ice Model version 2, Fichefet and Maqueda, 1997; Bouillon et al., 2009)
- Coupled every 3 hours with OASIS (Valcke, 2006)

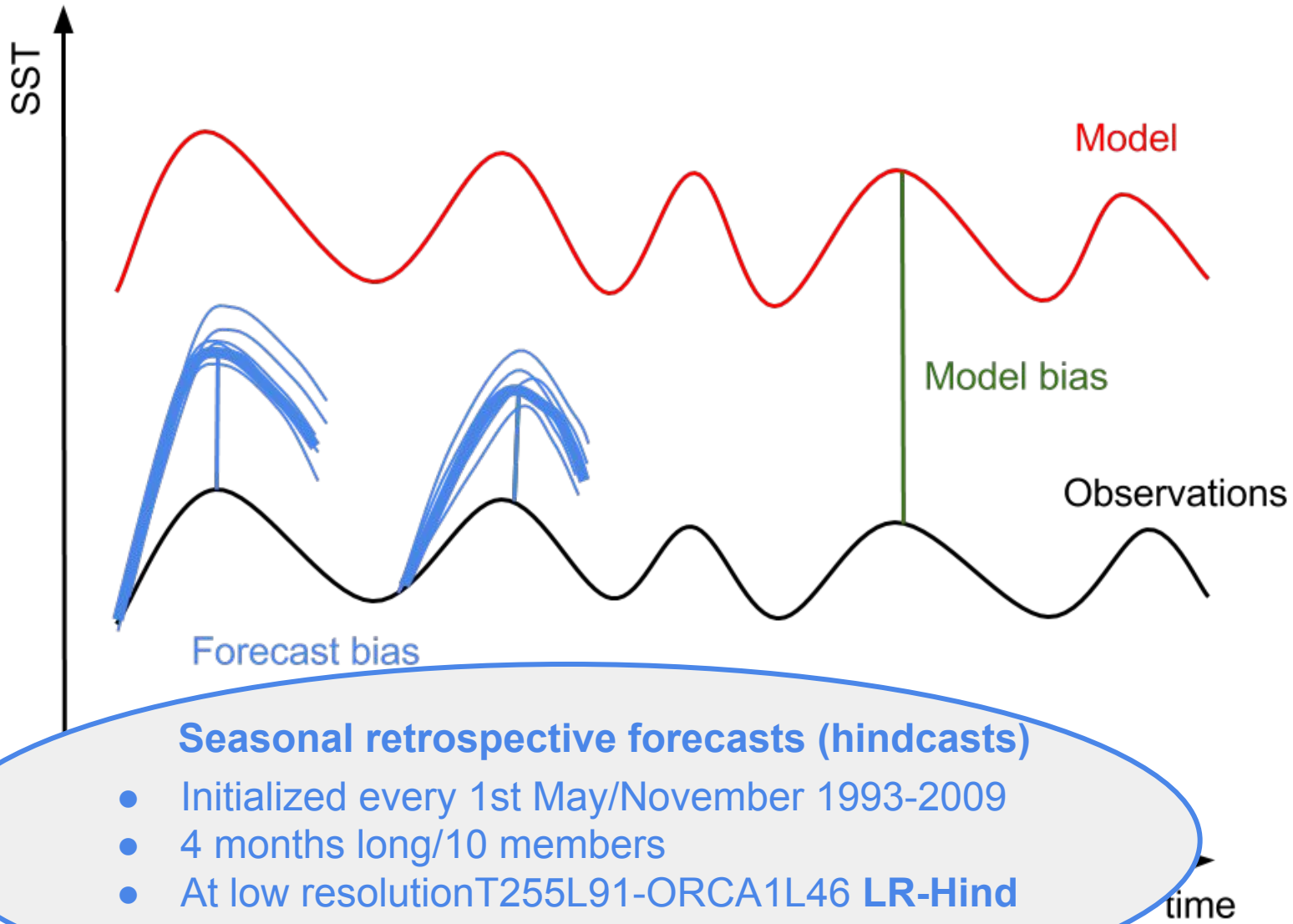
Methodological approach - Exps

Historical run **HR-Histo:**

- 1960-2000
- T511L91 - ORCA025L75



Methodological approach - Exps



Seasonal retrospective forecasts (hindcasts)

- Initialized every 1st May/November 1993-2009
- 4 months long/10 members
- At low resolutionT255L91-ORCA1L46 **LR-Hind**
- At high resolution T511L91-ORCA025L75 **HR-Hind**

Methodological approach - Exps

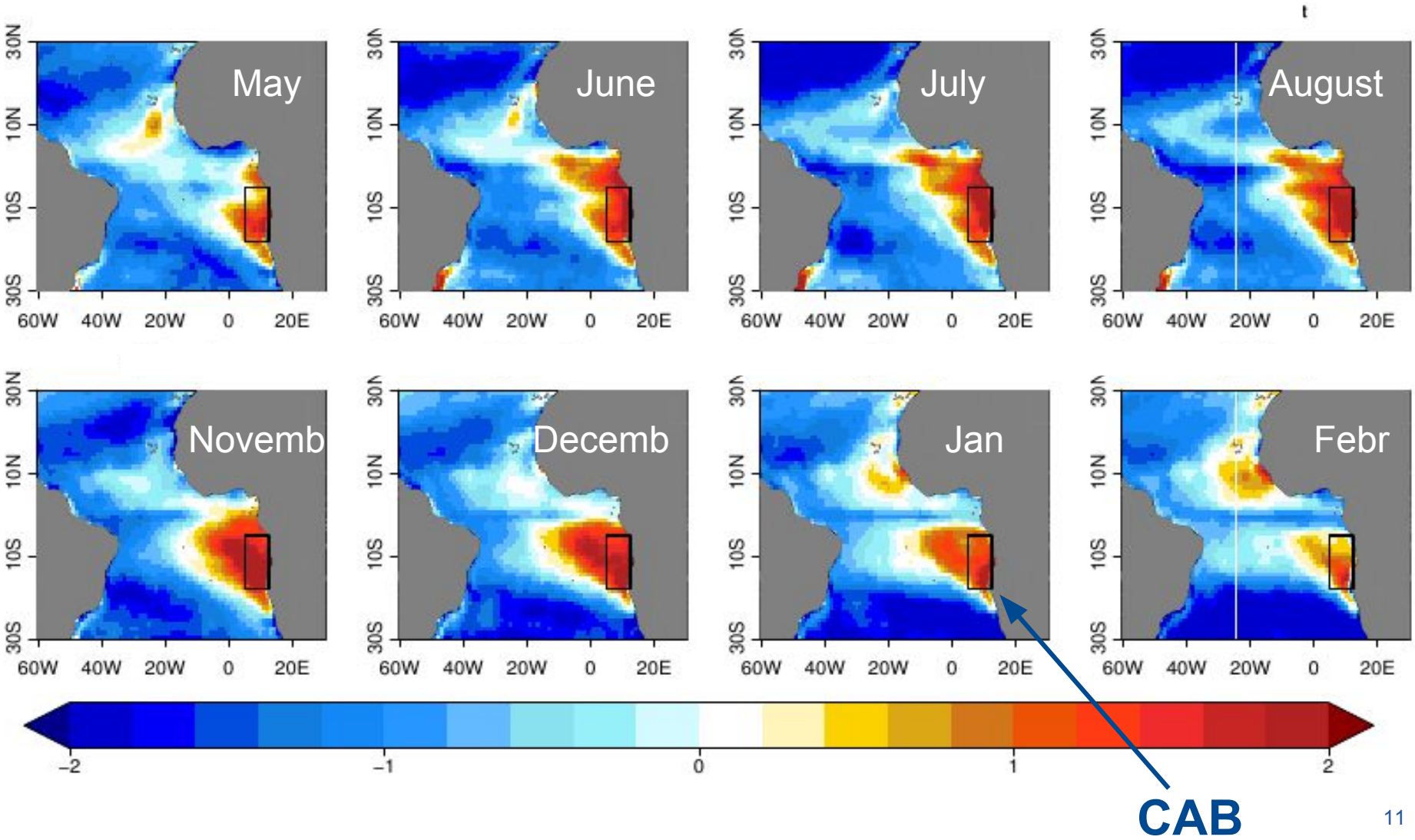
To evaluate the role of each model component and that of coupling

- Standalone ocean **LR-Ocean** and standalone atmosphere **LR-Atm** seasonal hindcasts

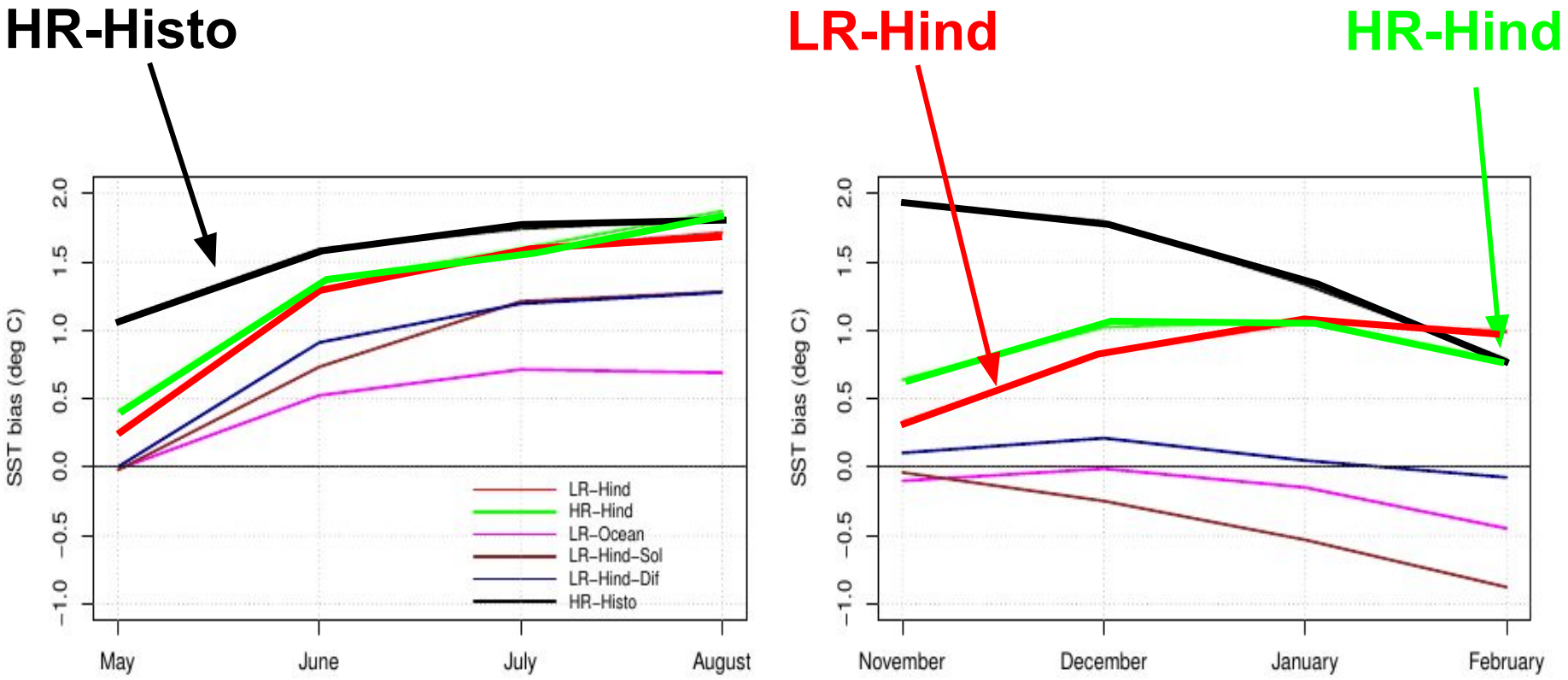
- Additional sensitivity experiments **LR-Hind-Sol** modified solar absorption and **LR-Hind-Dif** with increased vertical mixing

SST bias in EC-Earth

HR-Histo bias with respect to HadISST (Rayner 2003)



Bias development/Role of resolution



SST bias averaged over CAB

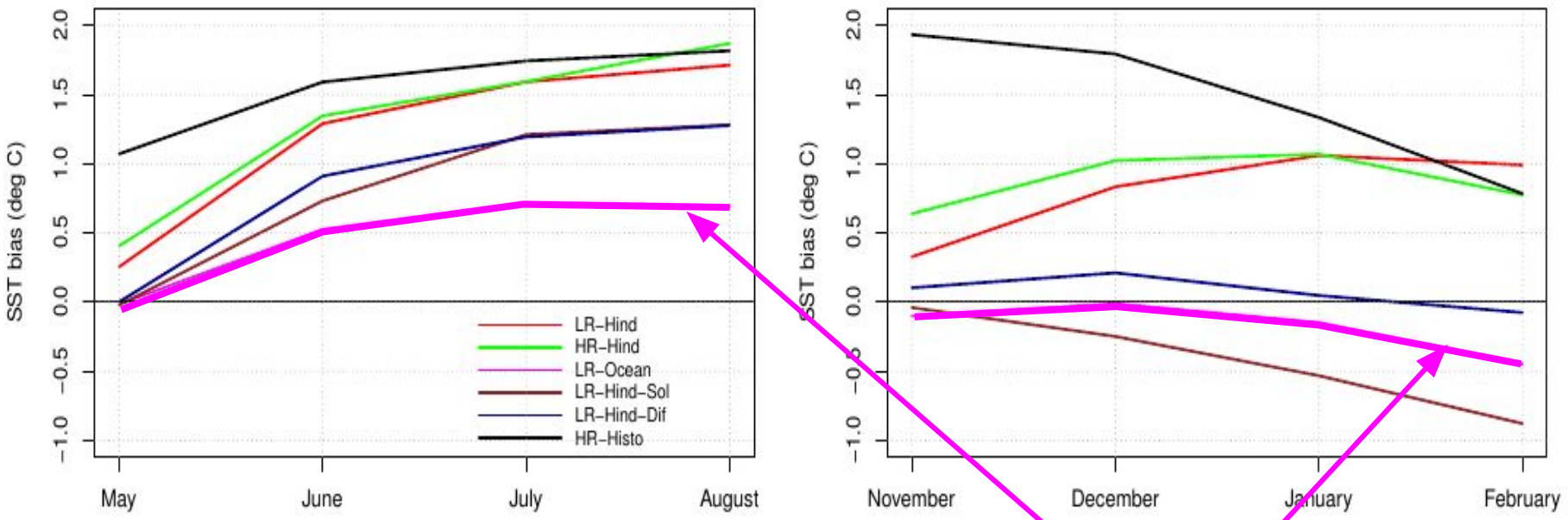
with respect to HadISST

Increasing model oceanic/atmospheric resolution does not impact much the Tropical Atlantic SST bias!

Role of ocean

SST bias averaged over CAB

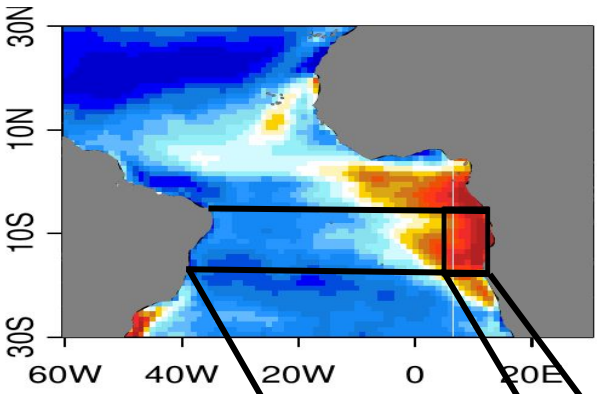
with respect to HadISST



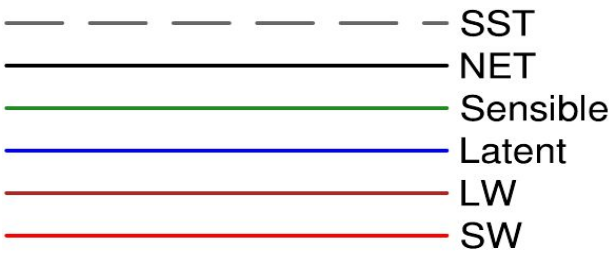
The standalone ocean has a weak only bias, and only in MJJA → atmosphere processes or atmosphere/ocean coupling mostly responsible for biases?

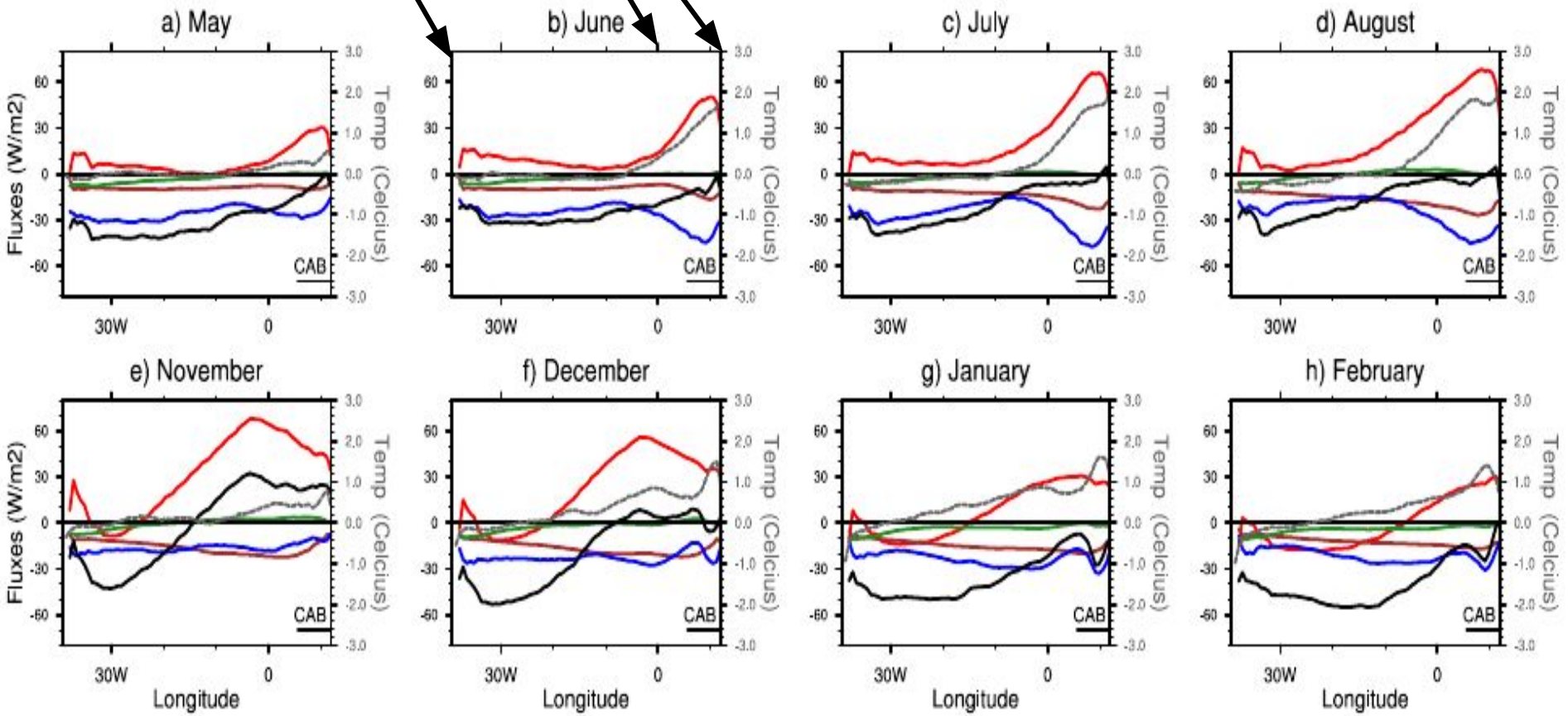
LR-Ocean

Biases in surface heat fluxes



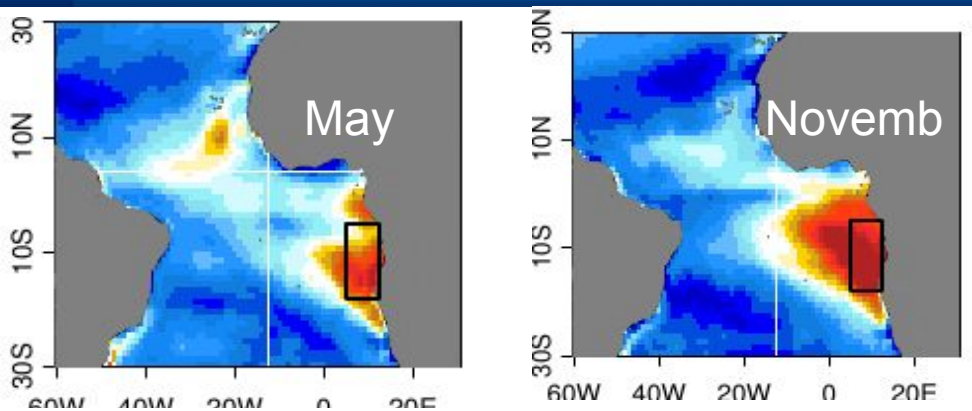
LR-Hind bias with respect to Tropflux (Kumar et al. 2012)





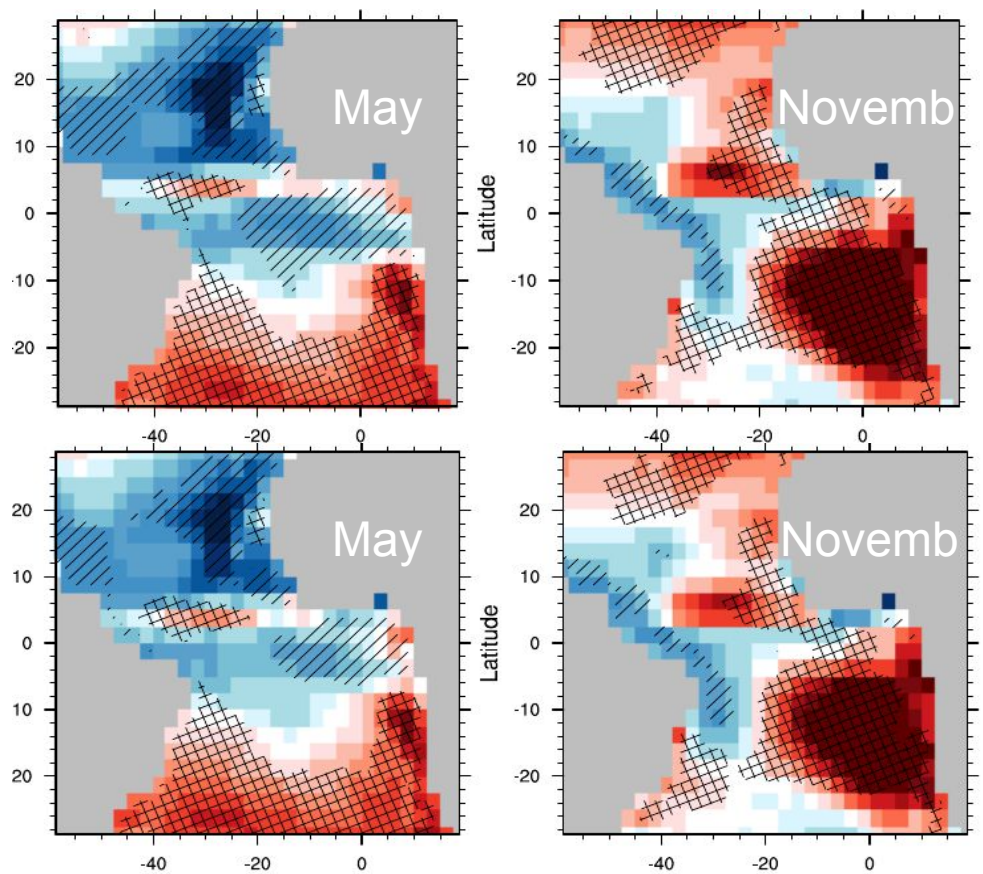
Origin of bias in solar fluxes

Bias in **SST**



LR-Hind

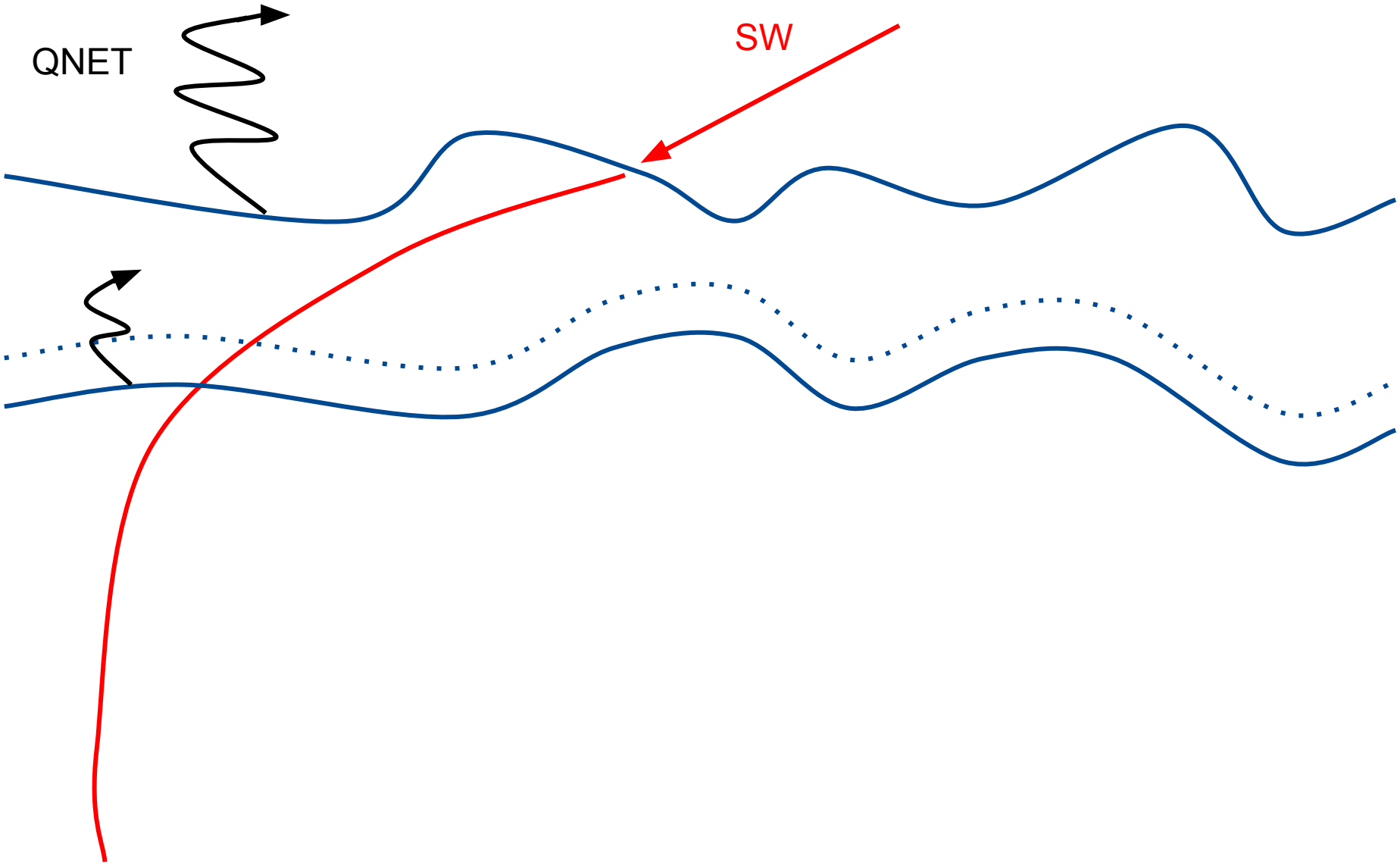
Bias in **solar fluxes** wrt TropFlux (colors) and in **daytime cloudcover** wrt ISCCP (Rossow 1996) hatched patterns



LR-Hind

LR-Atm

Stabilized water column

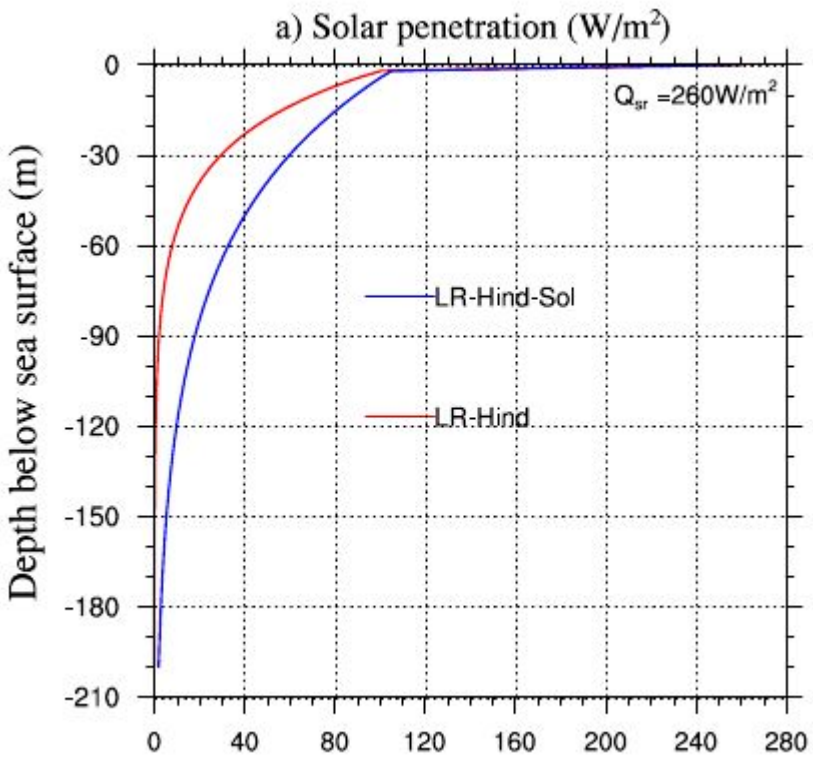


Solar absorption in the upper ocean

$$I_{pen}(z) = Q_{sr}\left(Re^{z/h1} + (1-R)e^{z/h2}\right)$$

Lengaigne et al. (2007)

λ>700nm 400nm<λ<700nm

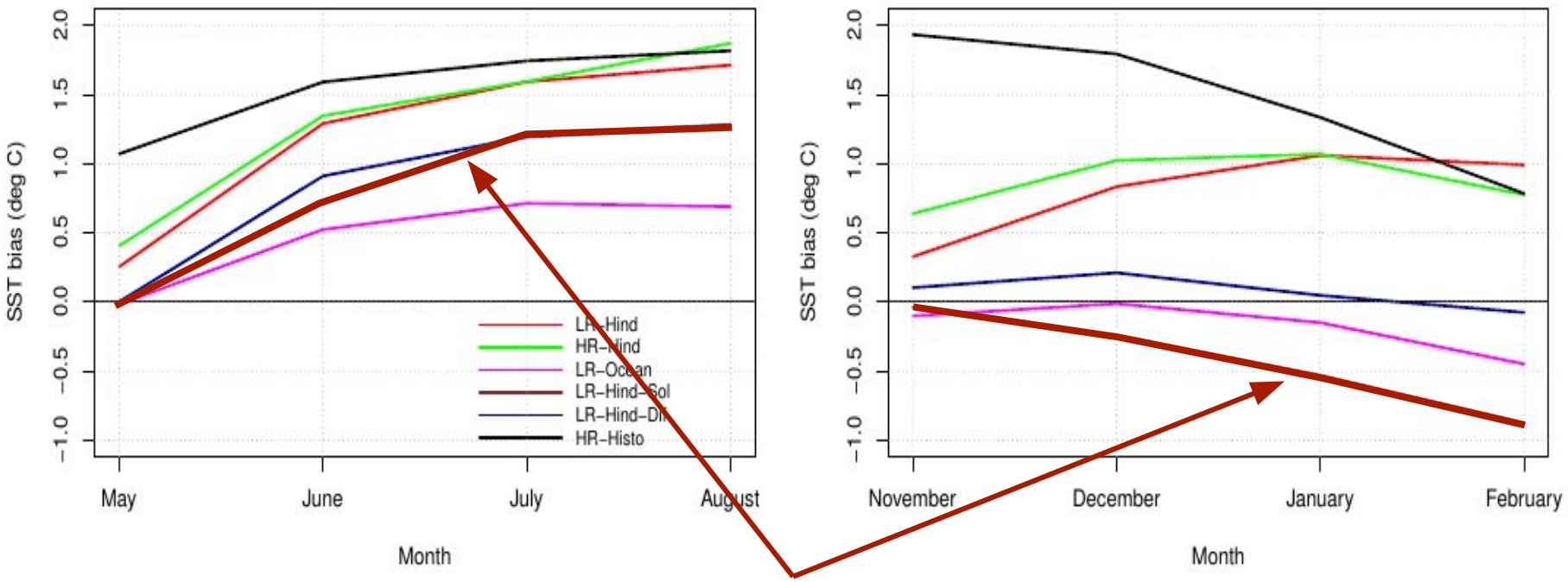


Sensitivity experiment **LR-Hind-Sol**: h2 is increased from 23m to 50m in (i.e. less absorption of solar radiation in the mixed layer)

Effect of less solar penetration in ML

SST bias averaged over CAB

with respect to HadISST



LR-Hind-Sol

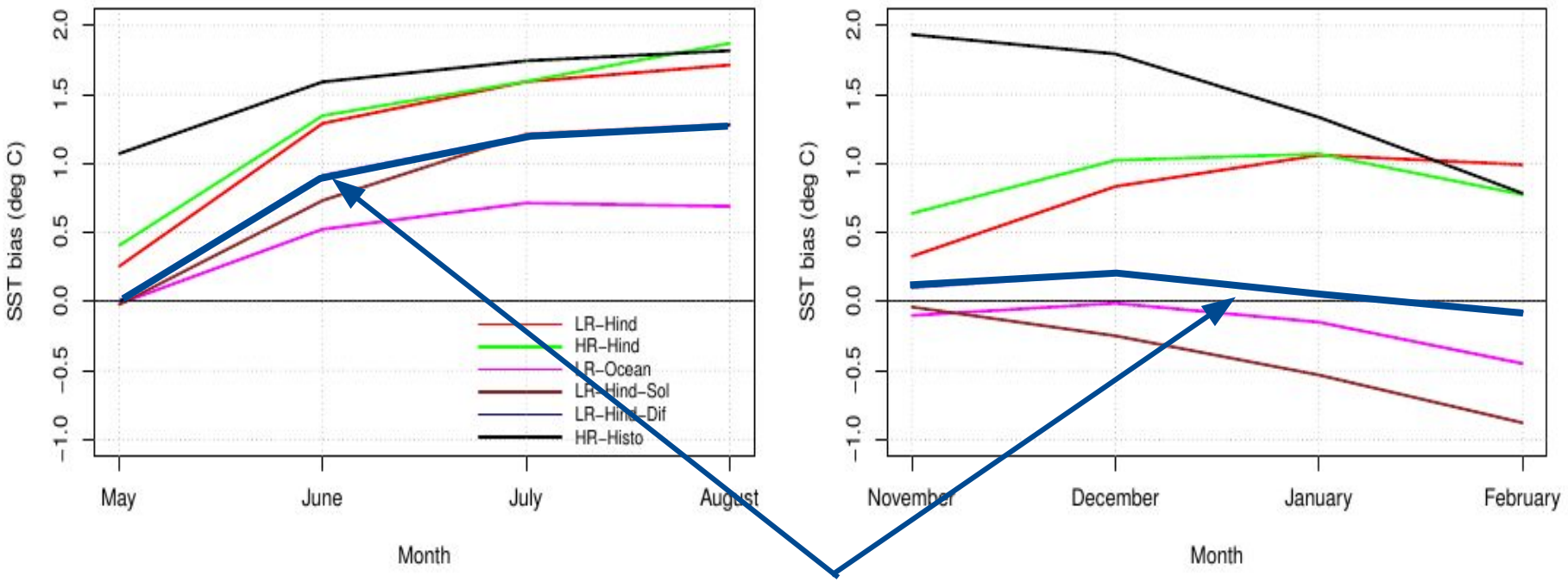
Net impact of modified solar absorption is cooling: weaker bias in summer, bias disappears in winter

Impact of turbulent mixing

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Sensitivity experiment **LR-Hind-Dif**: increased mixing below the mixed layer

TKE scheme (Gaspar et al. 2008, Madec 2008)



LR-Hind-Dif

Increasing turbulent mixing below the mixed layer also reduces SST bias

Conclusions

- EC-Earth 3.1 exhibits a warm SST bias in the eastern Tropical Atlantic similar to that of other CMIP models, **but with a weaker magnitude**.

- Increasing the horizontal resolution of both the atmosphere and ocean **results in minor improvements** in terms of horizontal extent and magnitude of the warm SST bias.

- The warm SST bias is found to be the result of an **excessive solar absorption** in the ocean mixed layer, linked to the excessive solar insolation due to **unrealistically low cloud cover**

- The bias is also partly a consequence of the **underestimation of the vertical turbulent mixing** by the ocean component; this limits the mixing of the surface layer with underlying colder water masses.

Outlook

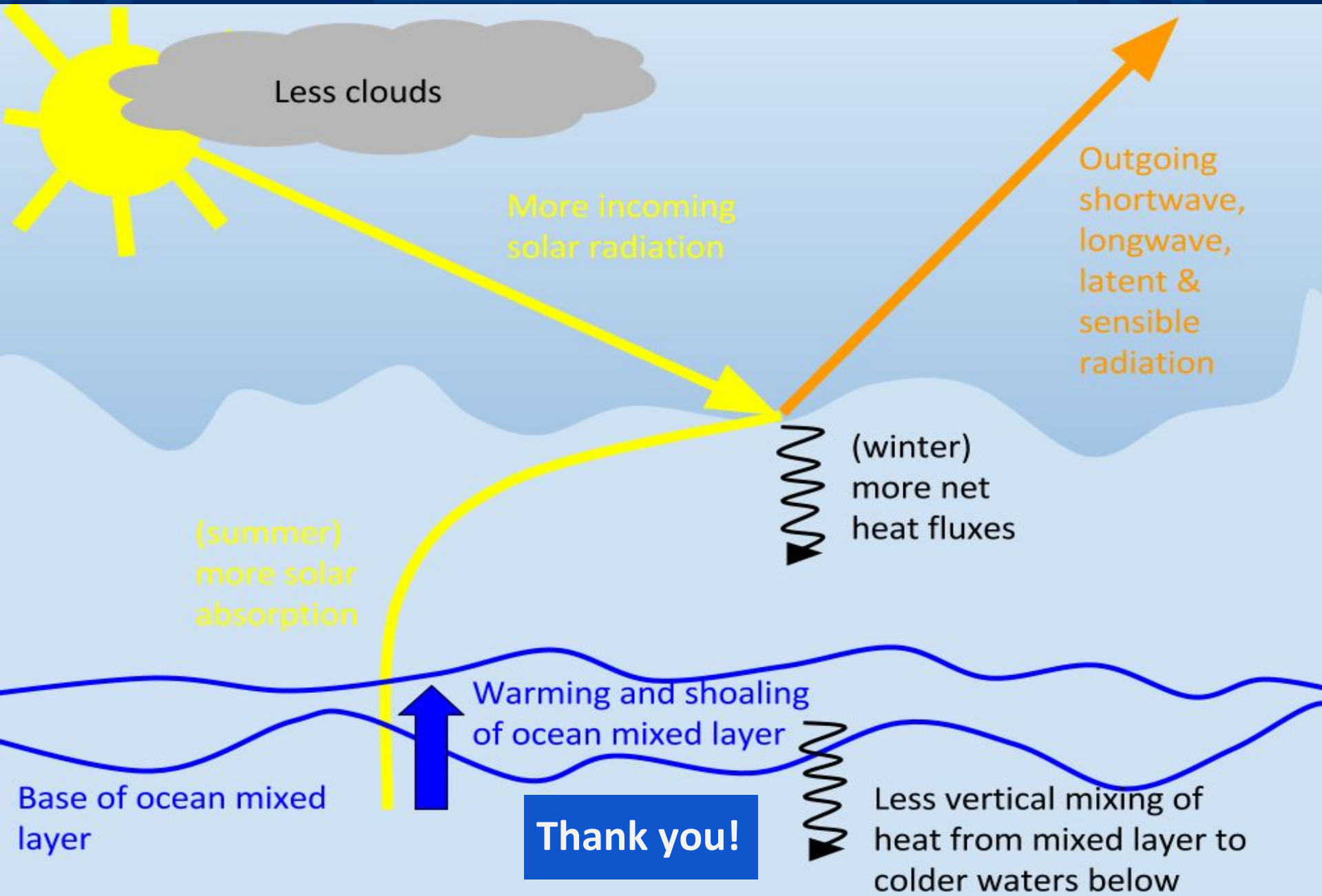
Steps suggested

- Atmosphere: better cloud representation at eastern boundaries
- Ocean: more sophisticated vertical physics, more realistic solar penetration schemes

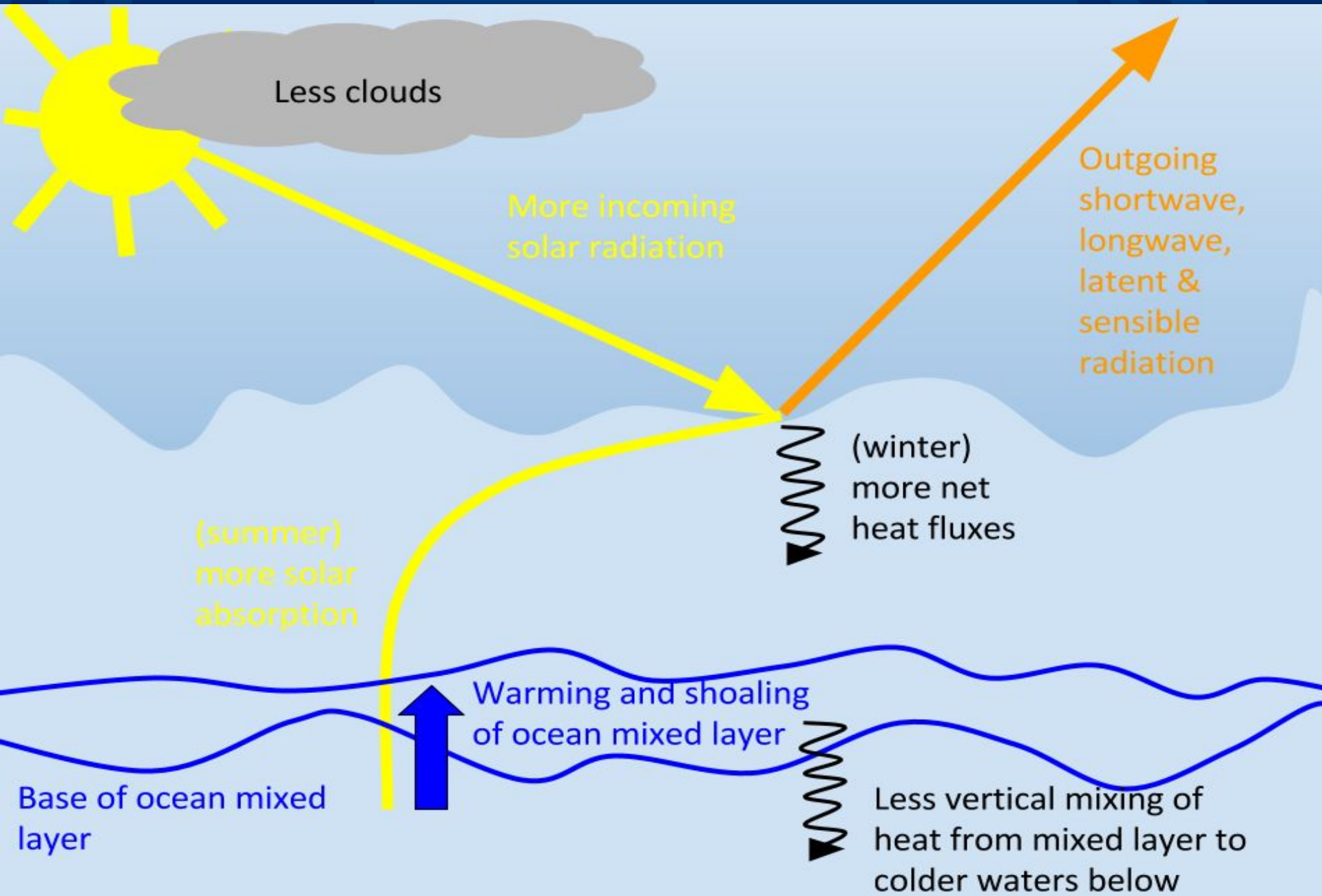
Outlook

- Impact on bias of sophisticated solar penetration scheme in NEMO that takes into account the spatial/temporal variations (due to ocean biological productivity)
- Turbulent mixing below the mixed layer: Impact on bias of spatially and temporally varying vertical mixing driven (for example) by near inertial motions generated from high frequency winds

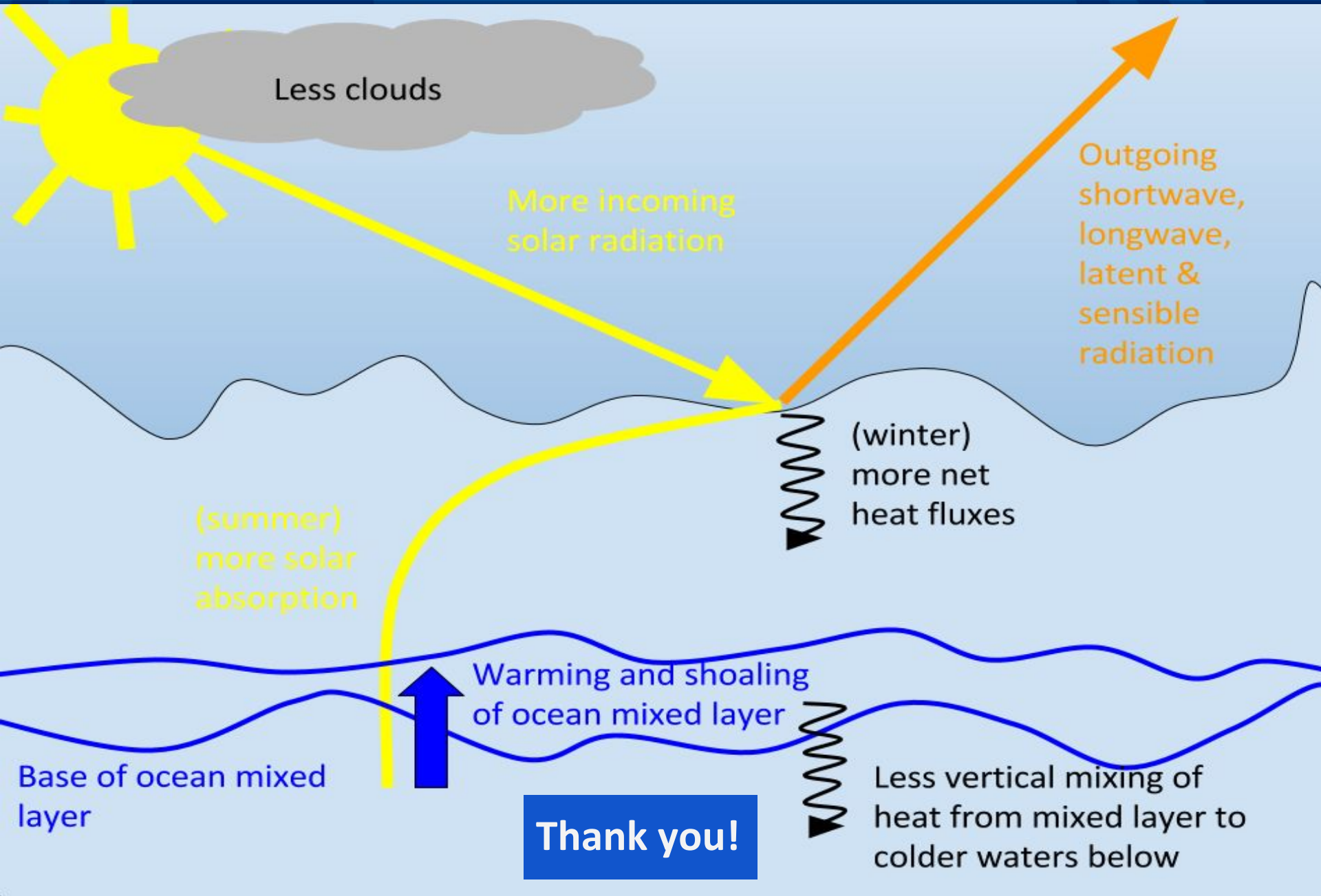
Mechanisms


Less clouds
More incoming solar radiation
Outgoing shortwave, longwave, latent & sensible radiation
(winter) more net heat fluxes
(summer) more solar absorption
Warming and shoaling of ocean mixed layer
Base of ocean mixed layer
Thank you!
Less vertical mixing of heat from mixed layer to colder waters below

Mechanisms


Less clouds
More incoming solar radiation
Outgoing shortwave, longwave, latent & sensible radiation
(winter) more net heat fluxes
(summer) more solar absorption
Warming and shoaling of ocean mixed layer
Base of ocean mixed layer
Less vertical mixing of heat from mixed layer to colder waters below

Mechanisms


Less clouds
More incoming solar radiation
Outgoing shortwave, longwave, latent & sensible radiation
(winter) more net heat fluxes
(summer) more solar absorption
Warming and shoaling of ocean mixed layer
Base of ocean mixed layer
Less vertical mixing of heat from mixed layer to colder waters below
Thank you!

Ocean mixed layer heat budget

$$\frac{\partial T}{\partial t} = \underbrace{\frac{1}{\rho_0 c_p h}\left[F_{sol}\left(I(0) - I(-h)\right)\right]}_{\text{solar penetration}} + \underbrace{\frac{1}{\rho_0 c_p h} F_{nsol}}_{\text{non-solar surface forcing}}$$

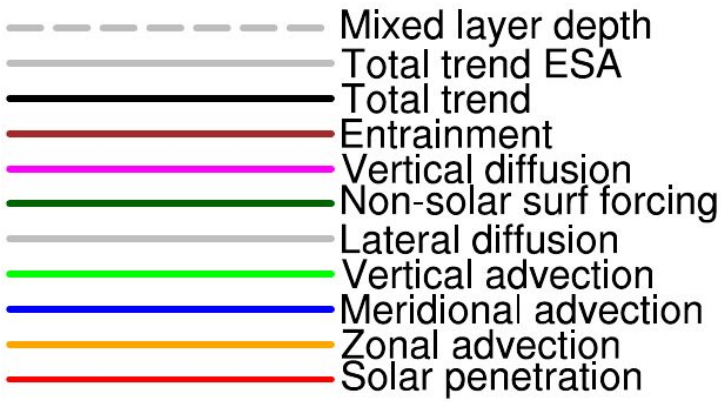
$$\underbrace{-u\nabla T}_{\text{zonal advection}} - \underbrace{v\nabla T}_{\text{meridional advection}} - \underbrace{w\nabla T}_{\text{vertical advection}} - \underbrace{\frac{1}{h} k_z \frac{\partial T}{\partial z}}_{\text{vertical diffusion}} +$$

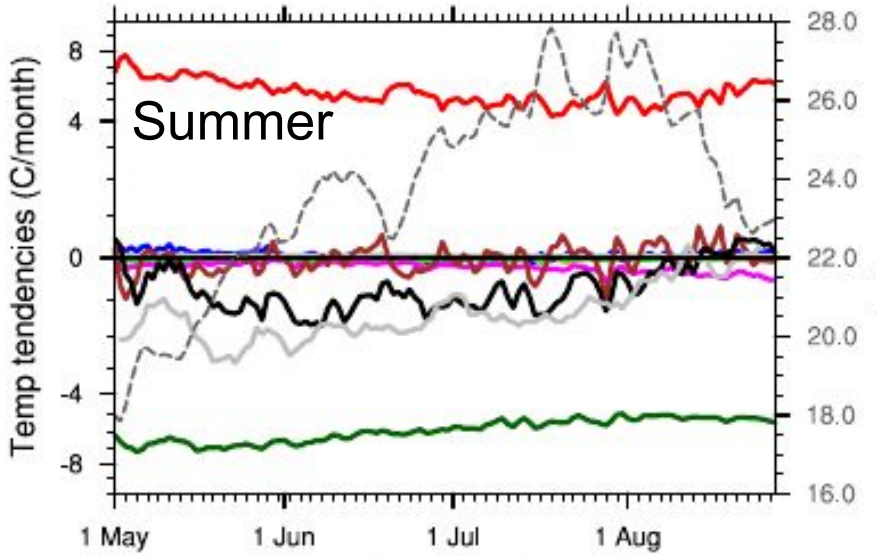
$$+ \underbrace{k_h \nabla^2 T}_{\text{lateral diffusion}} \underbrace{-\frac{1}{h}\left[T - T(-h)\right] w_e}_{\text{entrainment}}$$

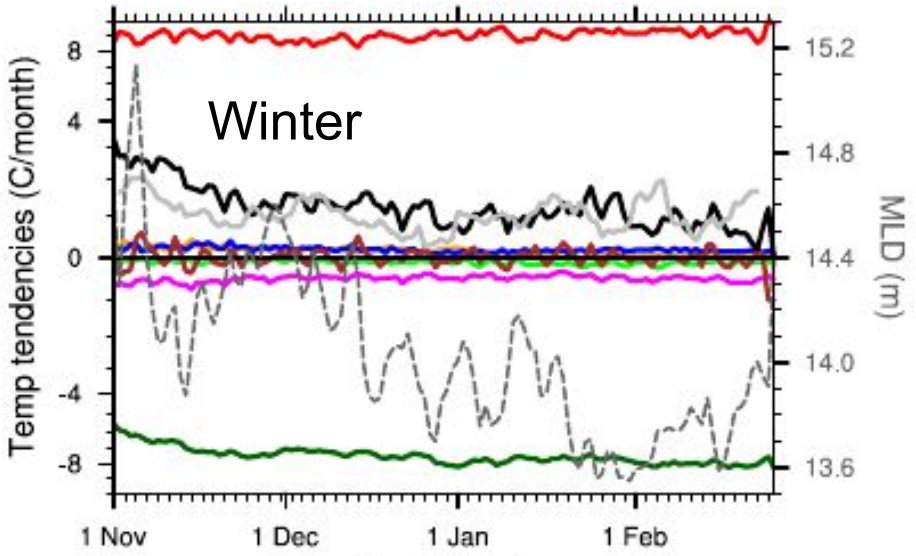
Ocean mixed layer heat budget

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

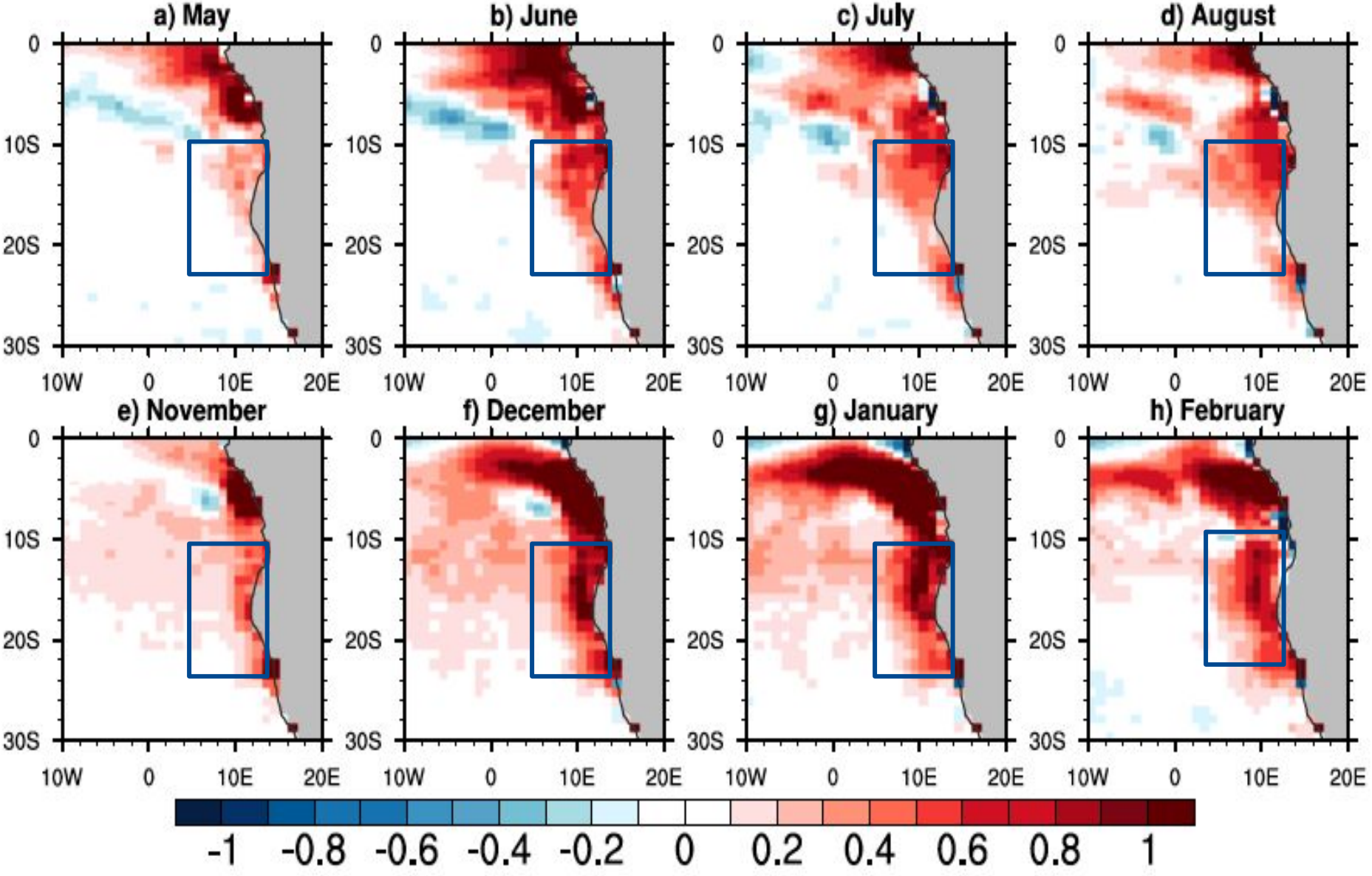
Daily mean temperature tendencies averaged in the ocean mixed layer and over CAB (∘C/month) for LR-Hind







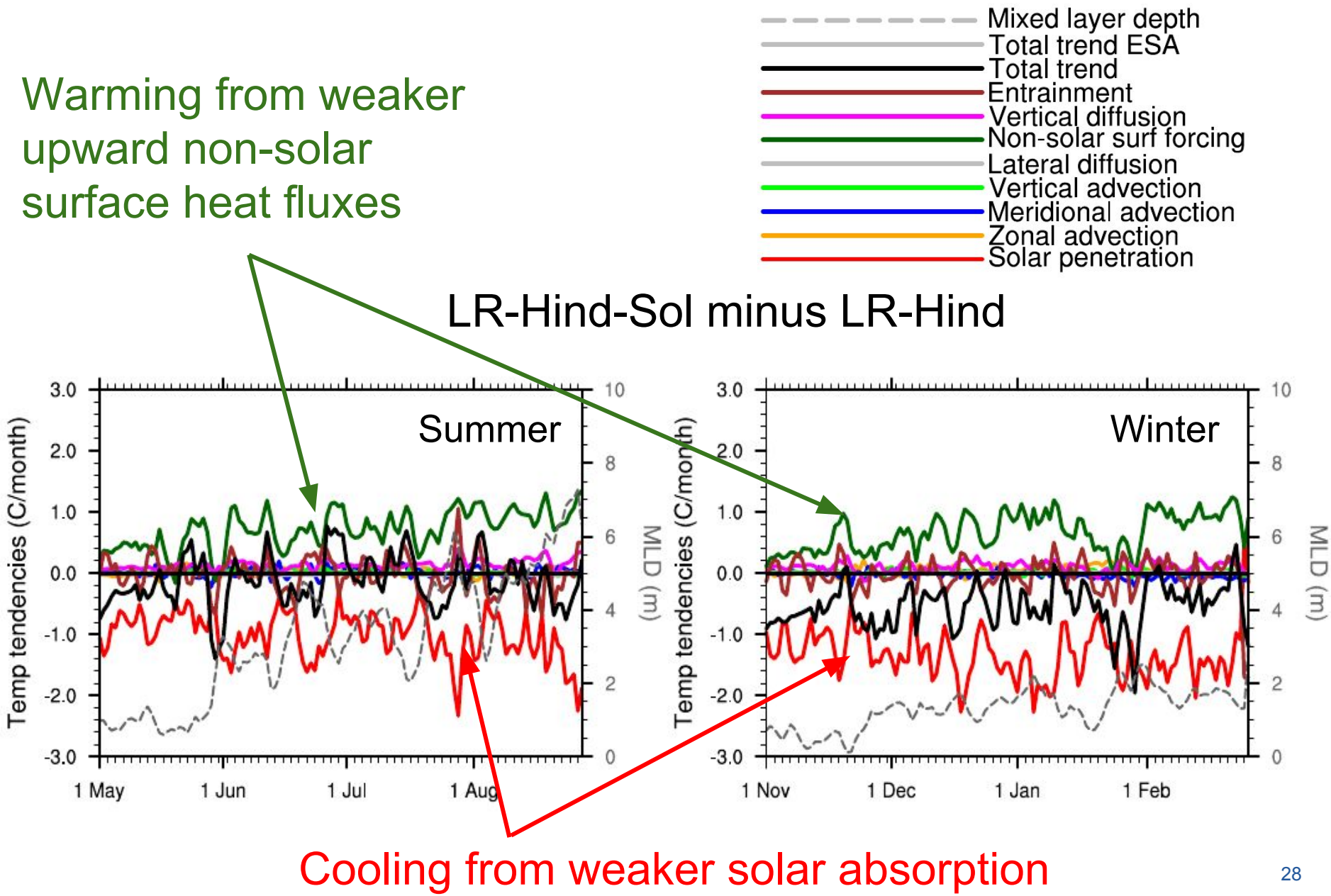
Ocean stabillity



Impact of less solar absorption in ML

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

Warming from weaker upward non-solar surface heat fluxes



Cooling from weaker solar absorption